UNITED STATES ARMY

# Level 2 Review of G2CRM for Single Use

*Southeast Crisfield, Somerset County, Maryland Hurricane and Storm Risk Management Feasibility Study*

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*Janes Island, Somerset County, Maryland Hurricane and Storm Risk Management Feasibility Study*

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**4/4/2016**

**Model Name:** Generation II Coastal Risk Model (G2CRM)
**Functional Area:** Coastal Storm Risk Management
**Model Proponent:** U.S. Army Corps of Engineers, Baltimore District (NAB) and USACE Engineer Research and Development Center (ERDC)
**Model Developer:** IWR / ERDC

The purpose of this document is to recommend the Generation II Coastal Risk Model (G2CRM) for a level two single approval for use on the following two studies:

I. *Southeast Crisfield, Somerset County, Maryland Hurricane and Storm Risk Management Feasibility Study*
II. *Janes Island, Somerset County, Maryland Hurricane and Storm Risk Management Feasibility Study*

This application of G2CRM was evaluated for technical quality, system quality, and usability. Based on the review, all criteria have been met for completion of a level two single use approval.

# 1 Background

## 1.1 Purpose of Model

G2CRM is a scalable planning risk based life cycle model intended for use in coastal regions to assist in rapid development of a tentatively selected plan. The model framework was developed in a series of workshops with USACE personnel with ongoing development guided by a working group representing IWR, HQ, ERDC, HEC, and RMC.

## 1.2 Model Description & Depiction

G2CRM is a desktop computer model currently under development by USACE intended for risk based life cycle modeling of non-sacrificial coastal protection systems. Model features include GIS integration and the capability to use available data from existing sources and corporate databases. At the time of this writing, it is not a certified model and is still under development.

## 1.3 Contribution to Planning Effort

G2CRM contributes to the planning effort by allowing the specification of existing, future without, and future with project conditions in order to characterize damages and costs while incorporating uncertainty.

## 1.4 Description of Input Data

Model input data include existing corporate databases, GIS shape-files, and/or excel template spreadsheets. Damage driving forces representing surge, waves, and winds are generated from wave models using ADCIRC or STWAVE. Modeled areas (MAs) are represented as shape files that contain assets that comprise the consequences. Protective system elements or coastal features that provide protection from inundation are represented as shape files. Assets are spatially located structures that contain structure and content value and are subject to damages.

## 1.5 Description of Output Data

Outputs are generated that provide overall results (damages, costs, etc.) per life cycle, or extremely detailed results for each incident of damage to an asset during the life cycle. Output formats include text files, csv files, and Spatialite databases. These outputs can be post-processed as needed or used to create GIS shape files to create spatial representations of damages and other activity.

## 1.6 Model Capabilities and Limitations

Currently, the model has the capability to estimate damages from inundation over the course of a life-cycle. Currently the model can represent the following:

- ❖ Current Capabilities
  - ✓ Inundation damages to structures and contents computed in constant and present value terms
  - ✓ The ability to specify certain rebuild and damage behavior
  - ✓ Represent the performance of PSE's that are subject to failure and repair
  - ✓ Representation of sea level change
  - ✓ Representation of plan alternatives at a point in time during the period of analysis
  - ✓ Life loss estimation
- ❖ Future Capabilities
  - ✓ Environmental consequence estimation

- ✓ Estimation of wave attack damage
- ✓ Incorporation of digital elevation models

❖ Limitations

- ✓ Estimation of erosion damages
- ✓ Representation of beach nourishment alternatives

## 1.7 Model Development Process

As mentioned previously, the model framework was assembled during a series of meetings between USACE personnel. Model has been developed using test situations with realistic data, but the application to the Janes Island and Southeast Crisfield studies represents its first application to a real study. Situations tested during development include New Orleans, Diamondhead Mississippi, and Freeport Texas. There are no documented results from these applications available.

The G2CRM architecture was developed using open source technology, and operates on information populated from GIS and other data sources.

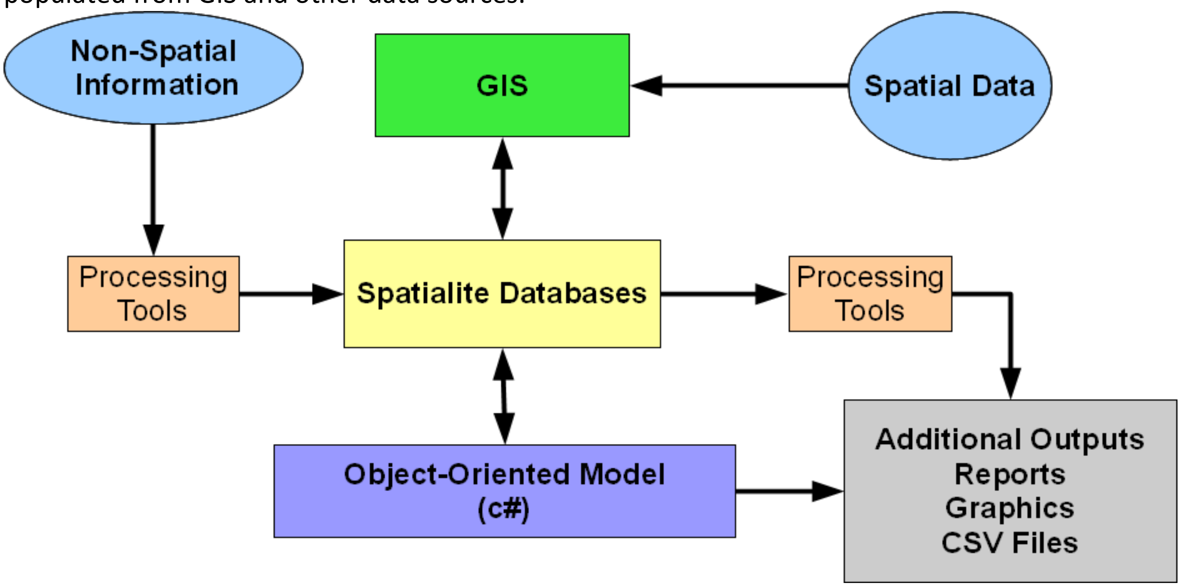


*Figure 1: G2CRM Architecture*

# 2 Technical Quality

"Model must be based on good science and theory and be modeled in computer code with a high degree of accuracy and precision. It must be verified that formulas, relationships, and calculations are correct. The logic of the model must be sensible, all analytical requirements for the application are satisfied, and the assumptions are fully documented." – EC 1105-2-412

## 2.1 Is the model based on well-established contemporary theory?

Yes. The model incorporates and updates many of the features of other USACE certified corporate models such as Beach-fx and Harbor-Sym. G2CRM is implemented as an object-oriented probabilistic life cycle analysis (PLCA) model using event-driven Monte Carlo simulation. This allows for incorporation and analysis of time-dependent and stochastic event-dependent behaviors such as sea level change, structure removal, and repetitive damages. The model is based upon driving forces (storms) that affect a coastal region (study area). The study area is comprised of individual sub-areas of different types that may interact hydraulically and may be protected by coastal defense elements that serve to shield the areas and the assets they contain from storm damage.

It was developed in the context of SMART planning, to get reasonably quick answers to assist in identifying the tentatively selected plan (TSP). The model is scalable in that different levels of detail can be used for the data that drives the model, with lower levels of detail at early stages of model application (fewer storms, aggregated assets) and more refined representations used as new data become available.

## 2.2 What are the critical components of the system and are they adequately represented?

Yes. The critical components of the system for this modeling effort are the as follows:

- Storms/hydrology
- Janes Island and Cedar Island Barrier Islands
- Approximately 2487 structures in the floodplain of Southeast Crisfield
- Seven mile tidal dike system

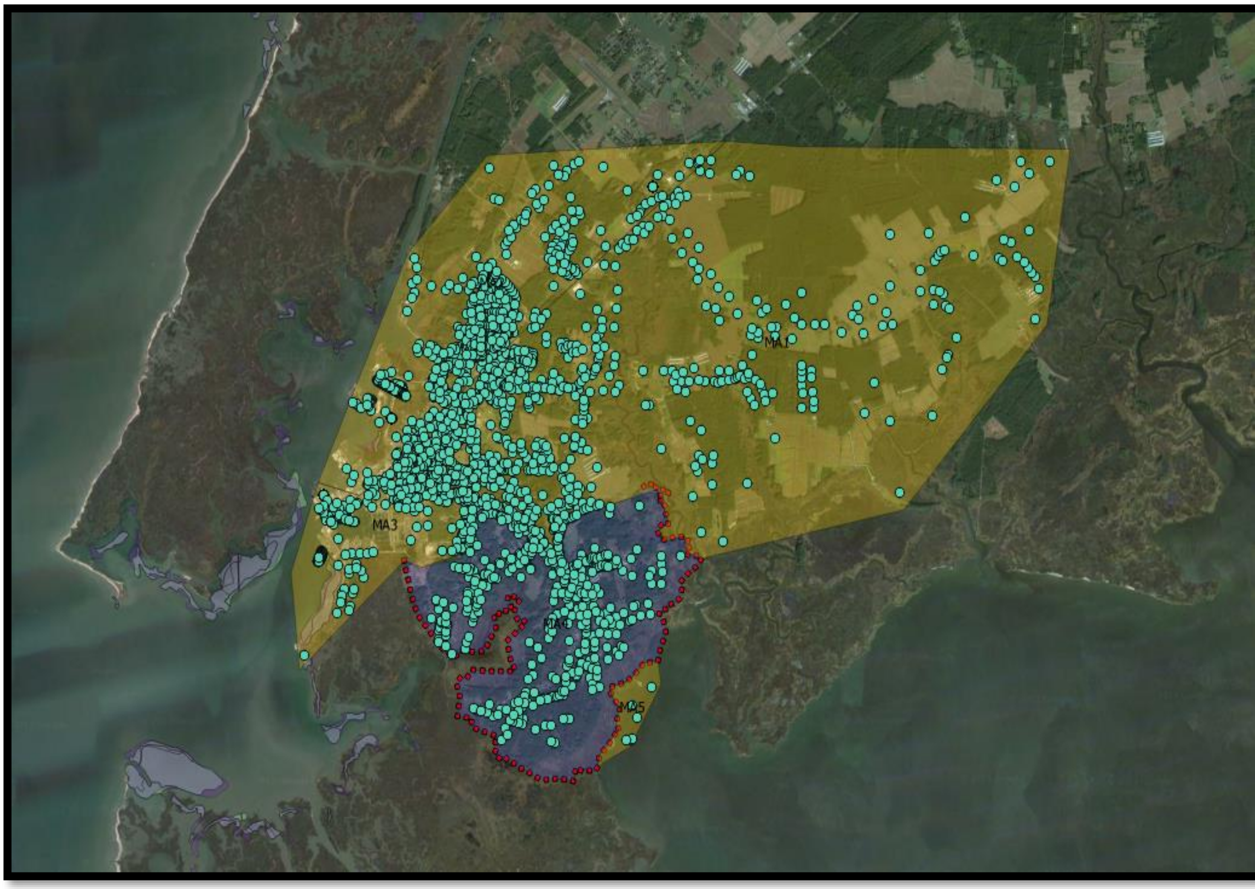


*Figure 2: Study Area*

Representation within the model framework is as follows:

- **Driving forces** - storm hydrographs (surge, waves, and winds) at locations, as generated externally from high fidelity storm surge and near shore wave models such as ADCIRC and STWAVE;

- **Modeled areas** (MAs) - areas of various types (polder, coastal upland, etc.) that comprise the overall study area. The water level in the modeled area is used to determine consequences to the assets contained within the area. This study is divided into five model areas; 1 protected, and 4 unprotected.
- **Protective system elements** (PSEs) - the infrastructure that defines the coastal boundary be it a coastal defense system that protects the modeled areas from flooding (levees, pumps, closure structures, etc.), or a locally developed coastal boundary comprised of bulkheads and/or hardened shoreline, or a more natural setting such as a marsh or typical estuarine, bay, or sandy beach boundary Protective system elements may be subject to failure and repair. For this study, the 7-mile tidal dike is defined as a bulkhead protective system element that is not subject to deterioration or loss of protective capacity due to water/wave action.
- **Interflow elements** - characterizing the water exchange possibilities between modeled areas, such as interior overflow structures between adjacent modeled areas. Interflow is not modeled in the Crisfield/Jane's Island study.
- **Assets** – spatially located entities that can be affected by storms. Damage to structure and contents is determined using damage functions. For structures, population data at individual structures allows for characterization of loss of life for storm events. The 2,487 structures in SE Crisfield are characterized here.

## 2.3 What are the analytical requirements?

In accordance with ER 1105-2-100, and reiterated in the NED Coastal Storm Risk Management Manual, the general analytical requirements are systems analysis, incremental analysis, separable elements, and life cycle analysis. Coastal storm risk reduction projects are typically required to analyze physical processes, coastal alterations, forecast shoreline changes, and estimate economic benefits and costs. Damage driving parameters typically analyzed are wave attack, inundation, and erosion. For these two studies, inundation (which includes the contribution of waves to water levels) is the damage driving parameter of concern.

## 2.4 Does the model address and properly incorporate the analytical requirements?

Yes. As stated previously, G2CRM is an event driven probabilistic life cycle simulation model. It captures the ability to represent the system, do incremental, and life cycle analyses. G2CRM does not presently have the capability to measure wave attack and erosion damages. It does have the ability to incorporate significant wave height into the water level stages. For these studies, a sandy beach with a sacrificial dune and berm is not part of the physical setting. All that is necessary is to analyze the effect of wave driven water levels on the exposed areas. The evaluation framework is as follows:

1. <u>Delineate Study Area</u> – Study area can be described in GIS and imported into G2CRM.
2. <u>Define the Problem</u> – G2CRM can be used to develop the existing condition and represent the problem quantitatively.
3. <u>Select Planning Shoreline</u> Reaches – Reaches are represented as Modeled Areas in the G2CRM environment.
4. <u>Establish Frequency Relationships</u> – Frequency relationships are developed by specifying storm seasons with an average number of tropical and extra tropical storms per year, and a suite of tropical and extra tropical storms with a relative probability of occurrence. Storm events are sampled from the population and over the course of a multi-iterative monte-carlo life cycle simulation, which establishes the water level frequency of occurrence relationship.
5. <u>Inventory Existing Conditions</u> – An inventory of assets with a triangular distribution of structure value, content value, 1st floor elevation, and rebuild time is represented in a GIS shape file and

imported into G2CRM. Protective system elements are also represented as GIS shape files and imported into G2CRM.

6. Develop Damage Relationships – Damage relationships are represented as damage functions which relate the water height above the 1st floor elevation to the percentage of value compromised. Damage functions are specified in an MS Excel spreadsheet and imported into G2CRM. G2CRM also provides the ability to characterize damage function uncertainty with a triangular distribution. This model feature (damage uncertainty) was not used in the Crisfield / Jane's Island study.
7. Develop Damage Frequency Relationships – The damage frequency relationship is established through the course of the G2CRM model simulation. Stochastic events generate water levels that inundate the asset inventory and cause damages based on the height of the first floor and the depth damage relationship.
8. Calculate Expected Annual Damages and Benefits – G2CRM returns present value damages for the future without and future with project condition.

## 2.5 What are the assumptions, the basis for those assumptions, and are the assumptions valid?

These are assumptions that have been put together by the reviewer based on information from the G2CRM model developer, review plan and plan formulation documentation to date.

### 2.5.1 G2CRM Simplifying Model Assumptions

- **Damage Driving Forces**
    - Externally generated storm surge hydrograph data is available.
    - Tidal effects and sea level change contributions are additive. Astronomical tide is used.
    - Simplified hydraulics with respect to how water levels appear in PSEs and modeled areas.
    - No terrain modeling is available at this time. The area being modeled is flat with minimal elevation change.
    - No 2-D flow is represented at this time. Representation of 2-D flow is not necessary for this application.
- **Protective System Elements (PSEs)**
    - PSE's mediate storm surge effect.
    - Flow through gates and levees is represented by a broad-crested weir equation (Not applied in this case).
    - Pumps have a single capacity independent of hydraulic head (Not applied in this case).
    - Dynamic behavior of sandy beaches is not represented.
    - Breakwaters are not explicitly represented, although their effects can be captured through external wave modeling.
- **Assets**
    - Assets exist at a single point and see only a single water level for a given event.
    - Assets are damaged by inundation only. Wave attack and erosion are not included as separate damage drivers at this time.
    - Loss of life assumptions are a simplified version of what is available in HEC-FIA. Detailed analysis of warning and evacuation strategies are expected to be incorporated in the model at some point in the future, but are not included at this time. (Loss of life is not included in this case, since it requires population data at the asset level, which was not provided by the PDT.)

### 2.5.2 Study Assumptions

- Protection afforded to Crisfield from the two barrier islands and the tidal dike are expected to degrade over time with respect to their morphology, however this effect is not represented in the model. NACCS save points capture the relevant wave and water level information to represent the driving forces.
- Tidal dike is represented in the model as a bulkhead and is not designated as capable of failing. However, the dike at its current height (2ft) provides very little protection relative to the 1st floor elevations of the assets within the MA.
- Repetitive Damages:
  - # Rebuilds: Structures can be rebuilt no more than two times per lifecycle to limit the incidence of repetitive damages from rebuilds. [This is specified in data; the number of allowable rebuilds is a data input variable, at the individual structure level.]

  - Rebuild Threshold: Structure must have at least 95% of a rebuild complete before the number of rebuilds is decremented [This is a global model input parameter, applied to all structures].
  - Damage Threshold: Structure must incur at least 50% damage before placed in rebuild status. This differentiates repairs from rebuilds [This is a global model input parameter, applied to all structures].
- Marina assets accrue damage based on storm and tide influenced water levels. The damage function for marina assets was constructed as follows:

| Water Level (ft.) | Damage % |
|---|---|
| 3 | 0 |
| 4 | 10 |
| 5 | 25 |
| 6 | 50 |
| 7 | 80 |
| 8 | 100 |

*Figure 3: Marina Damage Function*

## 2.6 What are the relevant USACE policies and procedures?

The relevant USACE policies and procedure guidance are ER 1105-2-100, EC 1165-2-212, EC 1105-2-412. Model framework has the ability to address the most relevant policies and procedures. The relevant policy guidance is as follows:

- ER 1105-2-100; Appendix E-133 to 144 / Chapter 3-4: Coastal Storm Risk Management sections
- EC 1165-2-212: Sea Level Change Considerations for Civil Works Programs:
- EC 1105-2-412: Assuring Quality of Planning Models: This guidance was used to formulate the questions to prove the technical quality, systems quality, and usability of G2CRM for applications to the Janes Island Southeast Crisfield Study.

## 2.7 Do analytical requirements and assumptions comply with policies and procedures?

The analytical requirements are in compliance with policies and procedures. The model does not handle wave attack or erosion at this time. The model does use significant wave height to influence the water levels used for the inundation damage driving parameter.

## 2.8 Do formulas and computations reflect relationships between system components?

Yes. Detailed model outputs describe the storm event, the water levels generated by that storm event, the type, value, and 1st floor elevation of any exposed assets, the water level height above the 1st floor elevation, and the asset susceptibility to damages.
The chain of events are as follows[1]:

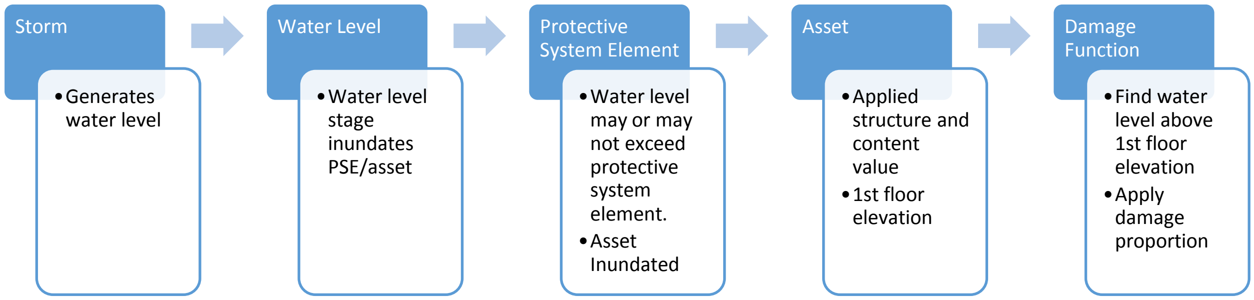


*Figure 4: Relationship between System Components*

Verification that the model captures the linkage between the systems components was performed by analysis of outputs from the IterationSummary.csv, Event.csv AssetDamageDetail.csv, and AssetDamageHistory.csv files. Influence of the protective system element was performed by increasing and decreasing the top elevation of the tidal dike and observing the impact on overall damages.

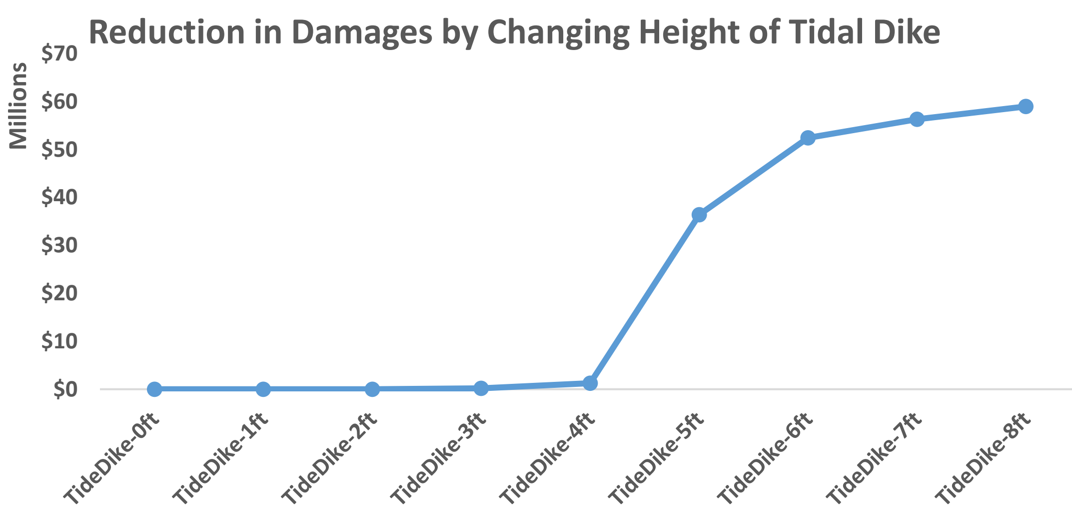


*Figure 5: Influence of Protective System Element*

It should be noted that the tidal dike elevation in the existing condition is ~2ft. Reducing the tidal dike top elevation produced no changes in the overall damages. No difference was noticed until the elevation was increased to 4ft.

## 2.9 Are formulas and computations correct?

Verification of computation correctness was performed as follows:

1. **Test-1:** Verification that the storms were generated within an acceptable range of the specified frequency and relative weighting.

[1] Note that, for unprotected MAs, the water level in not mediated by a PSE. For both the coastal upland and the unprotected MAs, a single water level is calculated for the entire MA, but the damage driving parameter at the asset level is a function of the asset first floor elevation as related to that water level.

2. **Test-2:** Isolating the effect of a storm event on an asset during the course of a single iteration / life cycle to check individual damage calculations.
3. **Test-3:** Verification of rebuild and damage threshold behavior
4. **Test-4:** Verification that the specific damages reported in the high resolution outputs match the generalized iteration level summaries.
5. **Test-5:** Characterization of uncertainty
6. **Test-6**: Sea level change

### 2.9.1 Test-1: Storm Seasons & Relative Storm Probabilities

This test was done to ensure the model samples tropical and extra-tropical storms at something close to the specified rate, while sampling among the 32 storms at close to their relative weighting. Table 1 and Table 2 provide results of storm sampling based on 300 iterations of a 54 year life cycle for tropical and extra-tropical storms respectively.

| Storm Number | Storm Identifier | # Times Selected over 300 Life Cycles | Expected # Times Selected | Specified Relative Frequency | Normalization | Returned Relative Frequency | % Error | Squared Error |
|---|---|---|---|---|---|---|---|---|
| 1 | Synthetic_0092 | 139 | 130.69 | 0.0095 | 14,631 | 0.010059 | 5.5% | 0.3077% |
| 2 | Synthetic_0107 | 2 | 0.84 | 0.0001 | 32,680 | 0.000145 | 57.7% | 33.3088% |
| 3 | Synthetic_0114 | 37 | 34.83 | 0.0025 | 14,612 | 0.002677 | 5.4% | 0.2944% |
| 4 | Synthetic_0136 | 247 | 256.99 | 0.0187 | 13,221 | 0.017874 | -4.5% | 0.2047% |
| 5 | Synthetic_0174 | 62 | 68.00 | 0.0049 | 12,542 | 0.004487 | -10.2% | 1.0359% |
| 6 | Synthetic_0180 | 149 | 158.55 | 0.0115 | 12,927 | 0.010782 | -6.9% | 0.4758% |
| 7 | Synthetic_0195 | 5 | 4.99 | 0.0004 | 13,773 | 0.000362 | -0.3% | 0.0011% |
| 8 | Synthetic_0198 | 25 | 20.69 | 0.0015 | 16,623 | 0.001809 | 16.9% | 2.8446% |
| 9 | Synthetic_0204 | 526 | 501.11 | 0.0364 | 14,439 | 0.038063 | 4.3% | 0.1844% |
| 10 | Synthetic_0271 | 1 | 1.07 | 0.0001 | 12,903 | 0.000072 | -7.1% | 0.5037% |
| 11 | Synthetic_0277 | 125 | 130.69 | 0.0095 | 13,157 | 0.009045 | -5.0% | 0.2531% |
| 12 | Synthetic_0278 | 147 | 170.72 | 0.0124 | 11,845 | 0.010638 | -16.7% | 2.7787% |
| 13 | Synthetic_0284 | 4 | 8.39 | 0.0006 | 6,557 | 0.000289 | -110.7% | 122.6341% |
| 14 | Synthetic_0314 | 131 | 130.69 | 0.0095 | 13,789 | 0.009480 | -0.2% | 0.0005% |
| 15 | Synthetic_0315 | 27 | 37.62 | 0.0027 | 9,872 | 0.001954 | -40.0% | 15.9813% |
| 16 | Synthetic_0393 | 557 | 528.87 | 0.0384 | 14,487 | 0.040307 | 4.6% | 0.2128% |
| 17 | Synthetic_0423 | 159 | 158.55 | 0.0115 | 13,795 | 0.011506 | -0.2% | 0.0003% |
| 18 | Synthetic_0524 | 52 | 58.14 | 0.0042 | 12,302 | 0.003763 | -12.3% | 1.5206% |
| 19 | Synthetic_0623 | 8 | 8.75 | 0.0006 | 12,579 | 0.000579 | -9.9% | 0.9725% |
| 20 | Synthetic_0625 | 4 | 6.47 | 0.0005 | 8,511 | 0.000289 | -62.4% | 38.9047% |
| 21 | Synthetic_0647 | 658 | 645.37 | 0.0469 | 14,025 | 0.047615 | 1.5% | 0.0215% |
| 22 | Synthetic_1007 | 170 | 158.55 | 0.0115 | 14,749 | 0.012302 | 6.3% | 0.3978% |
| **Total # Storms Sampled** | | **3235** | **3220.56** | **3220.56** | **13,819** | **Root Mean Square Error** | | **31.8262** |

*Table 1: Tropical Storm Sampling*

Tropical Storms had a specified frequency of .1988 storms /year on average. Based on the outputs, the returned frequency was .1997 storms per year.

RMS error is higher due to the differences between specified and returned frequencies for storms that are less likely to occur. **The RMS error drops to 6.6**% when low probability storms are excluded.

Figure 6: Storm FrequenciesFigure 6 provides greater detail on the differences between the expected and returned tropical storm frequencies.

| Storm Number | Storm Identifier | # Times Selected over 300 Life Cycles | Expected # Times Selected | Specified Relative Frequency | Normalization | Returned Relative Frequency | % Error | Squared Error |
|---|---|---|---|---|---|---|---|---|
| 23 | 1938012513 | 1,083 | 1,080 | 5 | 216.60 | 5 | -1.9% | 0.0370% |
| 24 | 1947030306 | 2,286 | 2,376 | 11 | 207.82 | 10 | -6.2% | 0.3883% |
| 25 | 1962030706 | 2,192 | 2,160 | 10 | 219.20 | 10 | -0.7% | 0.0051% |
| 26 | 1968111212 | 1,153 | 1,080 | 5 | 230.60 | 5 | 4.3% | 0.1818% |
| 27 | 1972110902 | 3,558 | 3,456 | 16 | 222.38 | 16 | 0.7% | 0.0052% |
| 28 | 1974120209 | 1,128 | 1,080 | 5 | 225.60 | 5 | 2.1% | 0.0459% |
| 29 | 1984022905 | 2,615 | 2,592 | 12 | 217.92 | 12 | -1.3% | 0.0171% |
| 30 | 1993031400 | 727 | 648 | 3 | 242.33 | 3 | 8.9% | 0.7920% |
| 31 | 2006111701 | 2,979 | 3,024 | 14 | 212.79 | 13 | -3.8% | 0.1407% |
| 32 | 2010020609 | 1,912 | 1,944 | 9 | 212.44 | 9 | -3.9% | 0.1535% |
| **Total # Storms Sampled** | | **19,633** | **19,440** | **Normalization Factor** | **220.77** | **Root Mean Square Error** | | **4.2031%** |

Extra –tropical storms had a specified frequency of 1.2 storms per year on average. The model returned a frequency of 1.21 storms per year on average.

The results show the specified and returned relative frequencies are close. **The RMS error is only ~ 4.2%**

*Table 2: Extra-Tropical Storm Sampling*

Figure 6 shows a graphic depiction of expected and returned frequencies for tropical and extra-tropical storms based on G2CRM outputs. The tropical storms (storm # 1-22) and the extra-tropical storms (storm # 23-32) are relatively close to each other. Based on this test, it can be concluded that the model is returning storms at close to the specified frequency and relative weighting. The model appears to be reflecting the specified frequency with natural variability. Figure 6: Storm FrequenciesFigure 6 provides greater detail on the differences between the expected and returned extra-tropical storm frequencies.

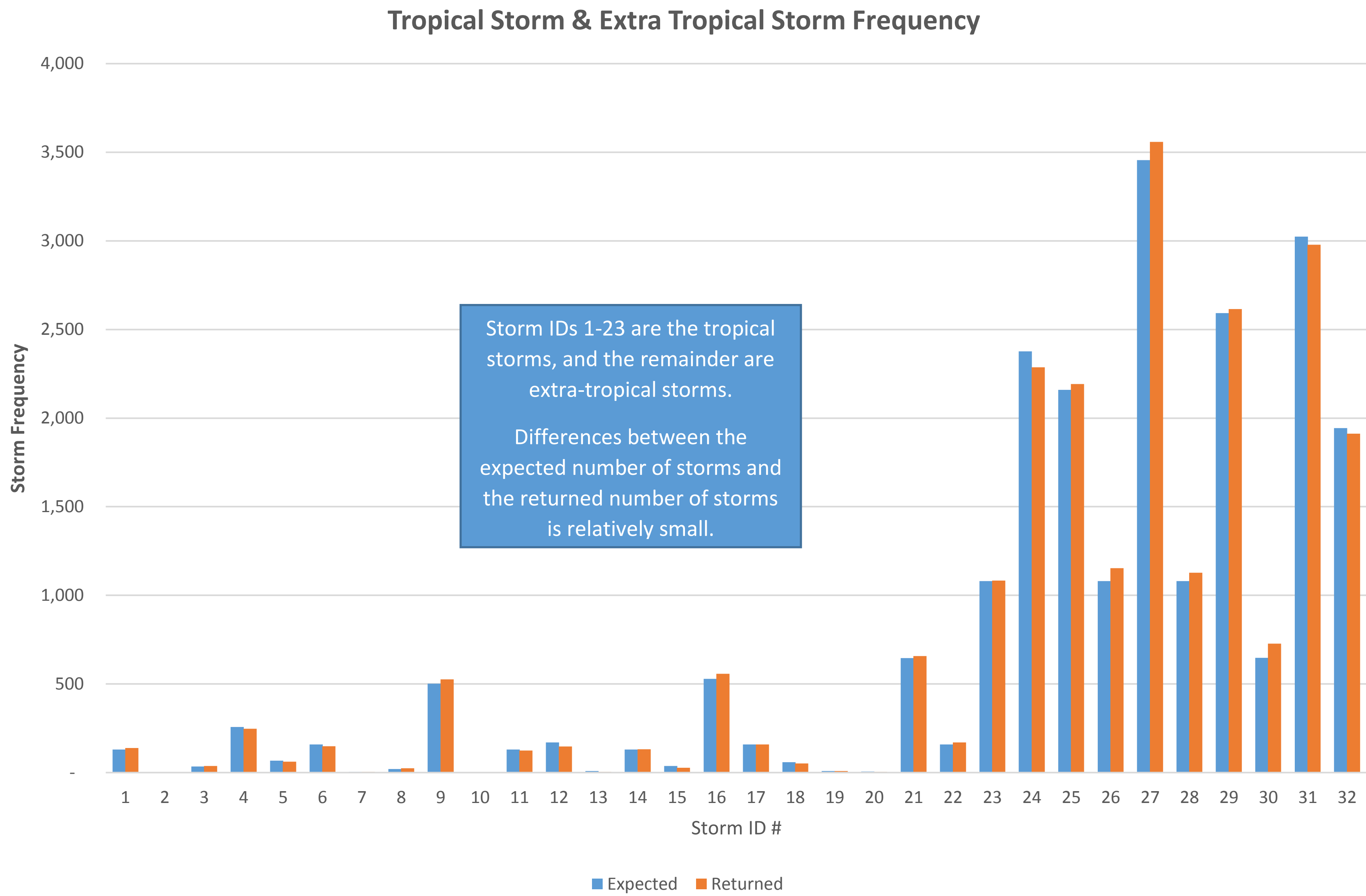


*Figure 6: Storm Frequencies*

### 2.9.2 Test-2: Damage Calculations

This test is comprised of the following checks to verify computational correctness.

- Water Level Stage generated by a storm event is measured against the 1st floor elevation
- Water level stage – 1st floor elevation = Damage Function Lookup Value
- Pre Storm Asset Value x Damage Function Lookup Value = Damage
- Damage x Present Value Factor = Present Value Damage

The outputs needed to make these checks reside in the AssetDamageDetail and AssetDamageHistory csv files. For the most part, structure and contents damages were able to be replicated. There were subtle differences between the G2CRM computations and the replicated values that are attributable to rounding error. Some irregularities with the damage function lookups were found.

The storm and water level generation event was included in the AssetDamageDetail output. This water level was compared to the 1st floor elevation to check the damage function lookup value. Water levels above the 1st floor are used to determine the damage function lookup value that gets returned and applied to the structure or contents value to calculate damages. Since the water level above the 1st floor is a continuous random variable while the values in the function are discrete, interpolation must be performed to return the appropriate damage function lookup values. Attempts to verify these calculations produced subtle differences that according to the developer, are attributable to the number of significant digits reported as the water level above the 1st floor. These differences are small (thousandths or ten thousandths) or non-existent in some cases. Uncertainty surrounding the damage function lookup values was not included within these tests because no triangular distribution of damage functions was specified.

Table 3 provide detail on the simulation time, the storm generated, the asset in question, and the structure and content damage function lookups. In addition, the table shows the 1st floor elevation, water level above the 1st floor, and the combined water level.

Table 4 provides detail on the pre-storm and post-storm structure value, the damages computed, and the present value damage computations. The values in the colored cells were checks of the computations. The differences between the values computed by the model and the checks are likely he result of the number of significant digits used in the 1st floor water level, and the damage function lookup value chosen. These differences are relatively insignificant[2].

Attempts to verify the initial pre-storm structure value within the AssetDamageDetail.csv output file met some difficulty initially. The pre-storm structure value contained the same value as the pre-storm contents value[3]. However, this does not mean an error within the calculations. Pre-storm values were calculated by adding the end of storm structure and content value to the estimated structure and content value losses. These values were similar to those found in the AssetValueHistory file.

The AssetValueHistory.csv iteration column reports an iteration value of 0, skips 1 and goes to two for the initial value. This is a minor error, and one could assume iteration 0 is iteration 1. However, this error should be corrected in the outputs to alleviate confusion[4].

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[2] Since this writing, the model developer has made changes to G2CRM to increase the number of significant digits in both of these random variables.

[3] This issue has since been corrected according to the model developer.

[4] This issue has also been corrected by the developer.

| DaysFromStart | Storm | AssetTextID | StructureDamageLookup | ContentsDamageLookup | Ground Elevation | FirstFloorElevation | WaterLevelAboveFirstFloor | CombinedWaterLevel |
|---|---|---|---|---|---|---|---|---|
| 24.3294 | 1938012513 | 2004894474 | 0.1727 | 0.2955 | 2.3 | 2.65 | 1.45 | 4.1 |
| 389.9067 | 1938012513 | 2004894474 | 0.1718 | 0.2937 | 2.3 | 2.65 | 1.44 | 4.08 |
| 670.9632 | 1938012513 | 2004894474 | 0.2051 | 0.3602 | 2.3 | 2.65 | 2.1 | 4.75 |
| 802.8391 | 1938012513 | 2004894474 | 0.1887 | 0.3274 | 2.3 | 2.65 | 1.77 | 4.42 |
| 994.3011 | Synthetic_0204 | 2004894474 | 0.1009 | 0.1518 | 2.3 | 2.65 | 0.51 | 3.15 |
| 1012.284 | 2006111701 | 2004894474 | 0.1903 | 0.3305 | 2.3 | 2.65 | 1.81 | 4.45 |
| 1025.245 | 1974120209 | 2004894474 | 0.1932 | 0.3364 | 2.3 | 2.65 | 1.86 | 4.51 |
| 1083.292 | 1947030306 | 2004894474 | 0.0752 | 0.1004 | 2.3 | 2.65 | 0.25 | 2.9 |
| 1347.106 | Synthetic_0277 | 2004894474 | 0.1936 | 0.3372 | 2.3 | 2.65 | 1.87 | 4.52 |
| 1858.998 | 1938012513 | 2004894474 | 0.1933 | 0.3365 | 2.3 | 2.65 | 1.87 | 4.51 |
| 3323.511 | 1938012513 | 2004894474 | 0.172 | 0.2939 | 2.3 | 2.65 | 1.44 | 4.08 |
| 3554.909 | Synthetic_0278 | 2004894474 | 0.3152 | 0.5614 | 2.3 | 2.65 | 5.15 | 7.8 |
| 3932.491 | 1962030706 | 2004894474 | 0.1612 | 0.2723 | 2.3 | 2.65 | 1.22 | 3.87 |

*Table 3: Time, Asset, & Water Level Physical Description*

| DaysFromStart | AssetTextID | StructureValuePreStorm | StructureDamageLookup | ValueLossStructure | ValueLossStructureCheck | StructureValuePostStorm | PresentValueFactor | StructureLossPV | StructureLossPVCheck | NumberOfTimesRebuilt |
|---|---|---|---|---|---|---|---|---|---|---|
| 24 | 2004894474 | $182,868 | 0.1727 | $31,588 | $31,581 | $151,280 | 1.1288 | $35,655 | $35,657 | 0 |
| 390 | 2004894474 | $182,869 | 0.1718 | $31,423 | $31,417 | $151,446 | 1.0945 | $34,392 | $34,392 | 0 |
| 671 | 2004894474 | $182,868 | 0.2051 | $37,503 | $37,506 | $145,365 | 1.0689 | $40,086 | $40,087 | 0 |
| 803 | 2004894474 | $182,868 | 0.1887 | $34,508 | $34,507 | $148,360 | 1.0571 | $36,477 | $36,478 | 0 |
| 994 | 2004894474 | $182,868 | 0.1009 | $18,456 | $18,451 | $164,412 | 1.0401 | $19,196 | $19,196 | 0 |
| 1,012 | 2004894474 | $167,297 | 0.1903 | $31,830 | $31,837 | $135,467 | 1.0386 | $33,058 | $33,059 | 0 |
| 1,025 | 2004894474 | $140,830 | 0.1932 | $27,206 | $27,208 | $113,624 | 1.0374 | $28,224 | $28,224 | 0 |
| 1,083 | 2004894474 | $145,491 | 0.0752 | $10,938 | $10,941 | $134,553 | 1.0324 | $11,291 | $11,292 | 0 |
| 1,347 | 2004894474 | $182,868 | 0.1936 | $35,400 | $35,403 | $147,468 | 1.0096 | $35,742 | $35,740 | 1 |
| 1,859 | 2004894474 | $182,868 | 0.1933 | $35,343 | $35,348 | $147,525 | 0.967 | $34,177 | $34,177 | 1 |
| 3,324 | 2004894474 | $182,868 | 0.172 | $31,447 | $31,453 | $151,421 | 0.8547 | $26,878 | $26,878 | 1 |
| 3,555 | 2004894474 | $182,868 | 0.3152 | $57,641 | $57,640 | $125,227 | 0.8382 | $48,313 | $48,315 | 1 |
| 3,932 | 2004894474 | $182,868 | 0.1612 | $29,473 | $29,478 | $153,395 | 0.8119 | $23,930 | $23,929 | 2 |

*Table 4: Damage Computations & Present Value*

Present worth factor and present value calculations were successfully replicated and verified. Present worth factors are compounded / discounted on a daily basis before application to damage estimates.

#### 2.9.3 Test-3: Rebuilds and Damage Parameter Tests

G2CRM incorporates a "Rebuild Threshold" and "Damage Threshold" feature that allows the user to specify the when rebuilds occur during the life cycle. Rebuild Threshold is defined as the percentage of the rebuild that has to be accomplished before a rebuild event is counted against the total number of rebuilds allowed. Damage threshold is the percentage of the structure damage that must occur before the asset is placed in "rebuild status".

Figure 7 and Figure 8 provide details on the results of the rebuild and damage threshold tests. The results are in constant dollars.

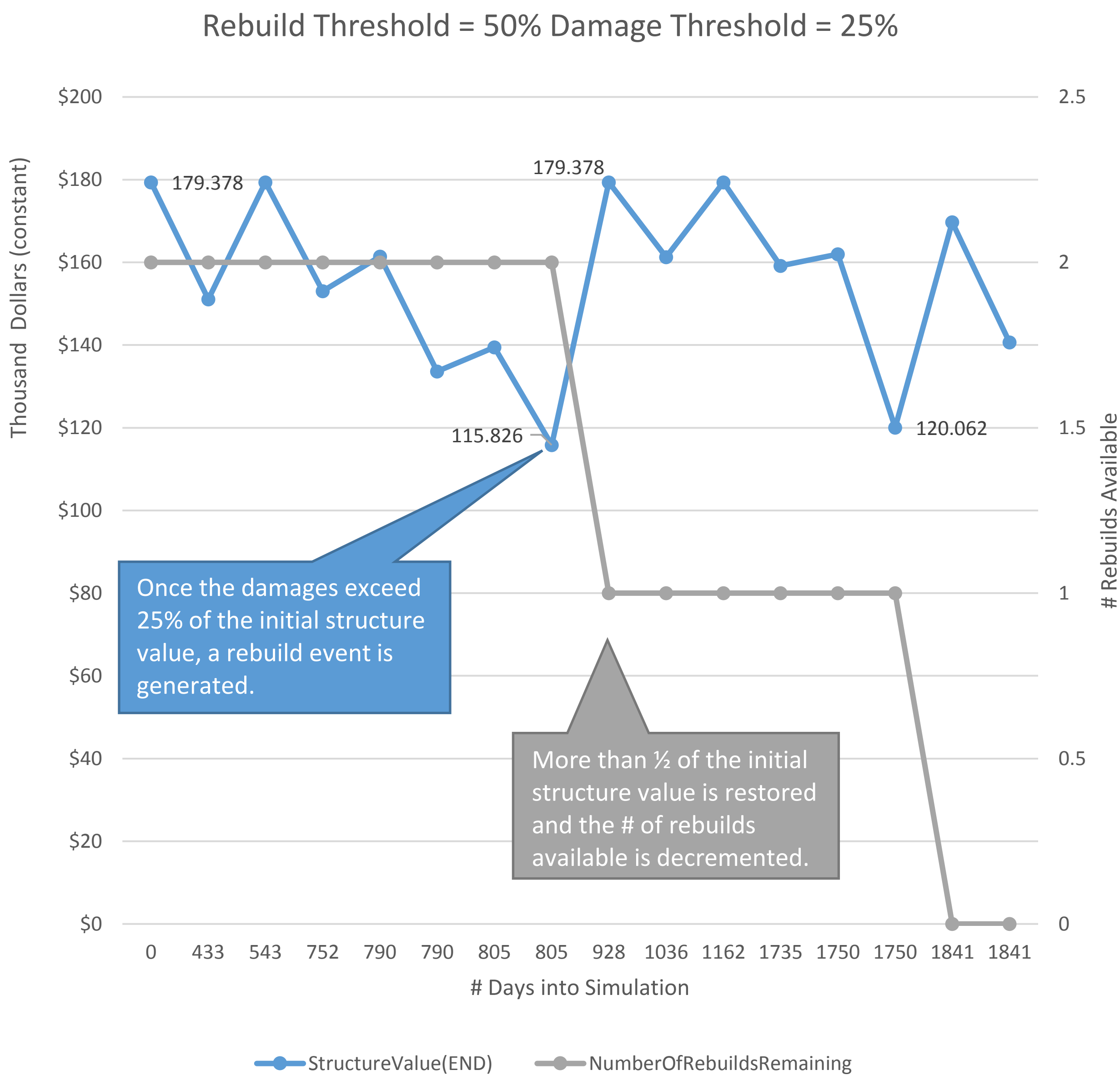


*Figure 7: Rebuild Threshold of 50% with a Damage Threshold of 25%*

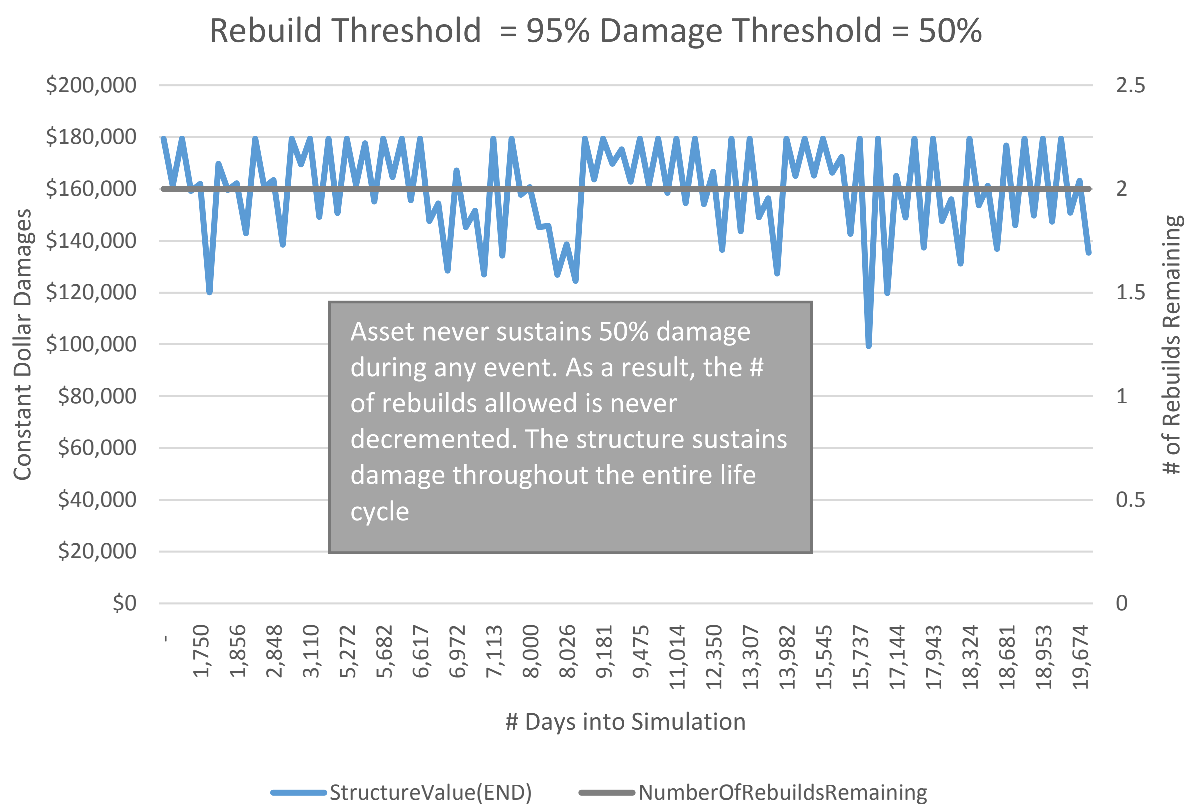


*Figure 8: Rebuild Threshold 95% Damage Threshold 50%*

The above two figures show structure damages for a single asset over a single lifecycle using different rebuild and damage threshold assumptions. Results appeared to be very sensitive to these two assumptions. In order to measure which threshold made the bigger difference, the results for the same asset and life cycle were isolated, for ten different tests. The results are shown in Table 5 in present value dollars.

| Damage(DT)/Rebuild(RT) Thresholds | Structure | Contents | Total |
|---|---|---|---|
| DT-0.1; RT-0.1 | 79,427 | 64,300 | 143,727 |
| DT-0.1; RT-0.25 | 89,292 | 69,848 | 159,141 |
| DT-0.1; RT-0.5 | 89,292 | 69,848 | 159,141 |
| DT-0.1; RT-0.75 | 89,292 | 69,848 | 159,141 |
| DT-0.1; RT-0.95 | 124,477 | 96,556 | 221,032 |
| DT-0.2; RT-0.95 | 155,298 | 118,898 | 274,196 |
| DT-0.5; RT-0.95 | 621,835 | 490,974 | 1,112,809 |
| DT-0.5; RT-0.1 | 621,835 | 490,974 | 1,112,809 |
| DT-0.75; RT-0.1 | 621,835 | 490,974 | 1,112,809 |
| DT-0.95; RT-0.1 | 621,835 | 490,974 | 1,112,809 |

*Table 5: Rebuild and Damage Threshold Tests*

Larger rebuild thresholds influence the results by allowing the structure to stay in the life cycle for a longer period of time. Damaged structures need to recover more of the asset value before the number of rebuilds allowed is decremented.

A larger damage threshold has a much more significant influence on the results relative to the rebuild threshold. As the damage threshold gets larger, the likelihood of a structure sustaining damage near the threshold during any event becomes less. The number of rebuilds allowed is less likely to be decremented and the structure is more likely to sustain damage over the entire life cycle. In this case illustrated in Table 5 and Figure 8, a structure worth around $179,378 with contents valued at $89,775 can sustain over $1.1 million in damage over the course of the life cycle.

### 2.9.4 Test-4: From Detailed to Summarized Outputs

This test was conducted to measure for any differences between the detailed outputs and the summarized outputs. Table 6 shows the difference between summarized results calculated from the AssetDamageDetail[5] file and outputs from the IterationSummary file for the same 10 iteration run for present value structure damages only. The differences are miniscule and amount to rounding error.

| Iteration | Calculated PV Structure Damages | Iteration Summary Present Value Structure Damage | % Difference |
|---|---|---|---|
| 1 | $658,269,626 | $658,269,647 | 0.00000% |
| 2 | $525,493,160 | $525,493,068 | 0.00002% |
| 3 | $570,164,509 | $570,164,600 | -0.00002% |
| 4 | $390,782,920 | $390,782,904 | 0.00000% |
| 5 | $516,377,115 | $516,377,034 | 0.00002% |
| 6 | $436,640,029 | $436,640,108 | -0.00002% |
| 7 | $425,075,143 | $425,075,139 | 0.00000% |
| 8 | $437,802,505 | $437,802,448 | 0.00001% |
| 9 | $519,521,155 | $519,521,116 | 0.00001% |
| 10 | $491,903,527 | $491,903,557 | -0.00001% |
| **Average Difference** | | | **0.000002%** |

*Table 6: AssetDamageDetail vs IterationSummary Outputs*

Table 7 was developed using summarized outputs from the AssetDamageDetail file. Present value structure and content damages for each iteration are shown. In addition, the output contains the total structure and content damages. Structure and content damages were summed and compared against the total. These differences also amount to rounding error.

| Iteration | Structure | Contents | Total | % Difference |
|---|---|---|---|---|
| 1 | $658,269,626 | $953,364,665 | $1,611,634,345 | -0.000003% |
| 2 | $525,493,160 | $702,118,500 | $1,227,611,623 | 0.000003% |
| 3 | $570,164,509 | $810,959,290 | $1,381,124,157 | -0.000026% |
| 4 | $390,782,920 | $512,078,364 | $902,861,159 | 0.000014% |
| 5 | $516,377,115 | $691,607,413 | $1,207,984,356 | 0.000014% |
| 6 | $436,640,029 | $572,681,014 | $1,009,321,092 | -0.000005% |
| 7 | $425,075,143 | $541,103,877 | $966,178,938 | 0.000008% |
| 8 | $437,802,505 | $591,786,000 | $1,029,588,584 | -0.000008% |
| 9 | $519,521,155 | $711,076,524 | $1,230,597,873 | -0.000016% |
| 10 | $491,903,527 | $698,385,102 | $1,190,288,654 | -0.000002% |

*Table 7: AssetDamageDetail Structure vs Content vs Total*

[5] The csv file was imported into an MS Access database and a query was used to sum up all the present value structure damages that occurred during an iteration.

### 2.9.5 Test-5 Uncertainty Test

As shown in Section 2.9, G2CRM allows natural variability to be characterized within the storm component of the system. The model also allows knowledge unknowns with respect to the asset to be characterized. G2CRM allows triangular distributions to be specified for the structure values, content values, rebuild times, and the 1st floor elevation. The purpose of this test is to compare the returned uncertainty to the specified uncertainty for structure value, content value, and 1st floor elevation for a particular structure.

Figure 9 illustrates the expected and returned 1st floor elevation uncertainty. Figure 10 and Figure 11 illustrate the expected and returned uncertainty for the structure and content value respectively. These results are based on 300 iteration runs isolating structure with asset text ID 2004894474. The structure and content value was pulled from the AssetDamageHistory output. First floor elevation values were pulled from the AssetDamageDetail output.

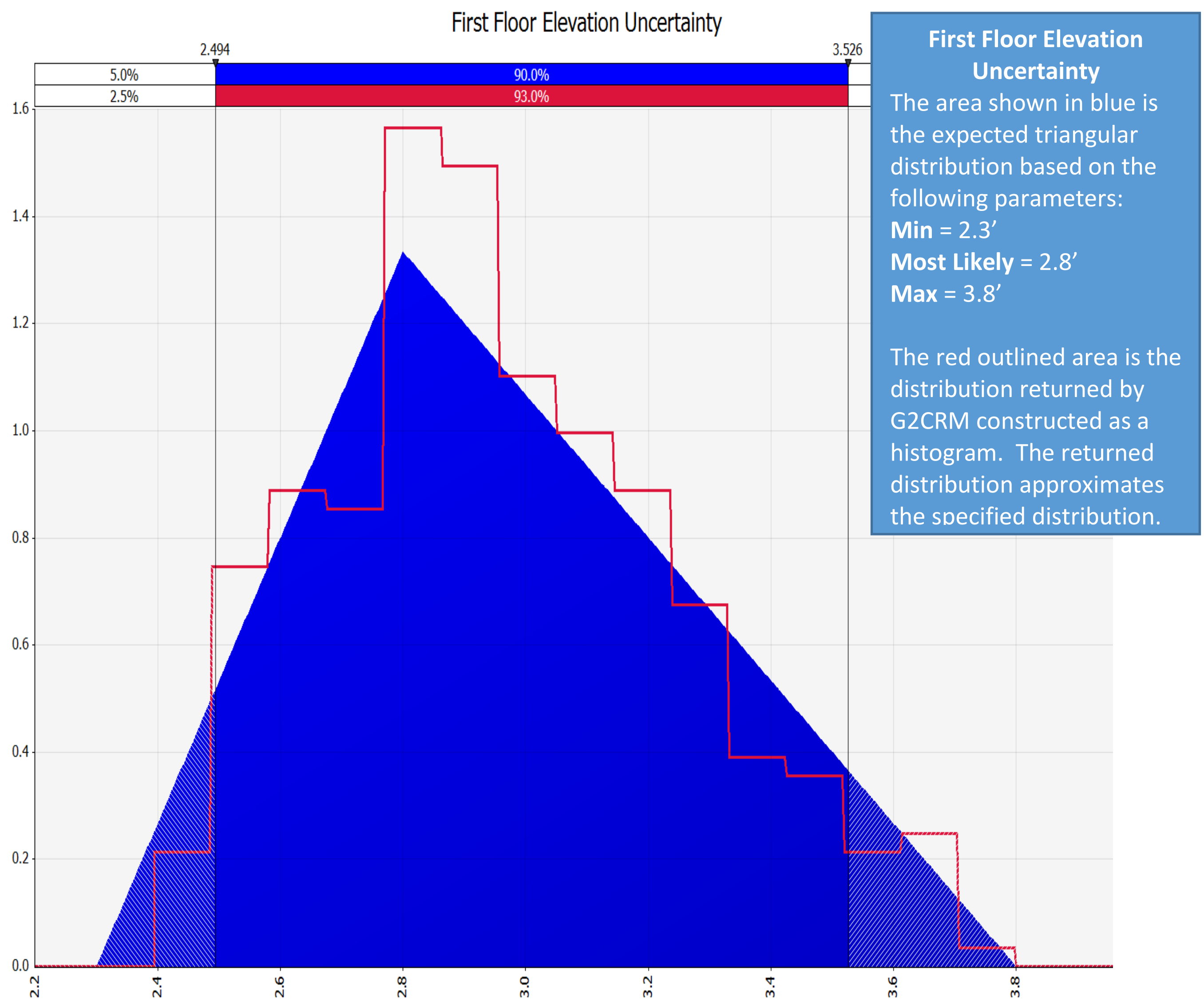


*Figure 9: First Floor Elevation Uncertainty*

**Structure Value Uncertainty**

The area shown in blue is the expected triangular distribution based on the following parameters:

**Min** = $132,800

**Most Likely** = $177,109

**Max** = $221,400

The red outlined area is the distribution returned by G2CRM constructed as a histogram. The returned distribution approximates the specified distribution.

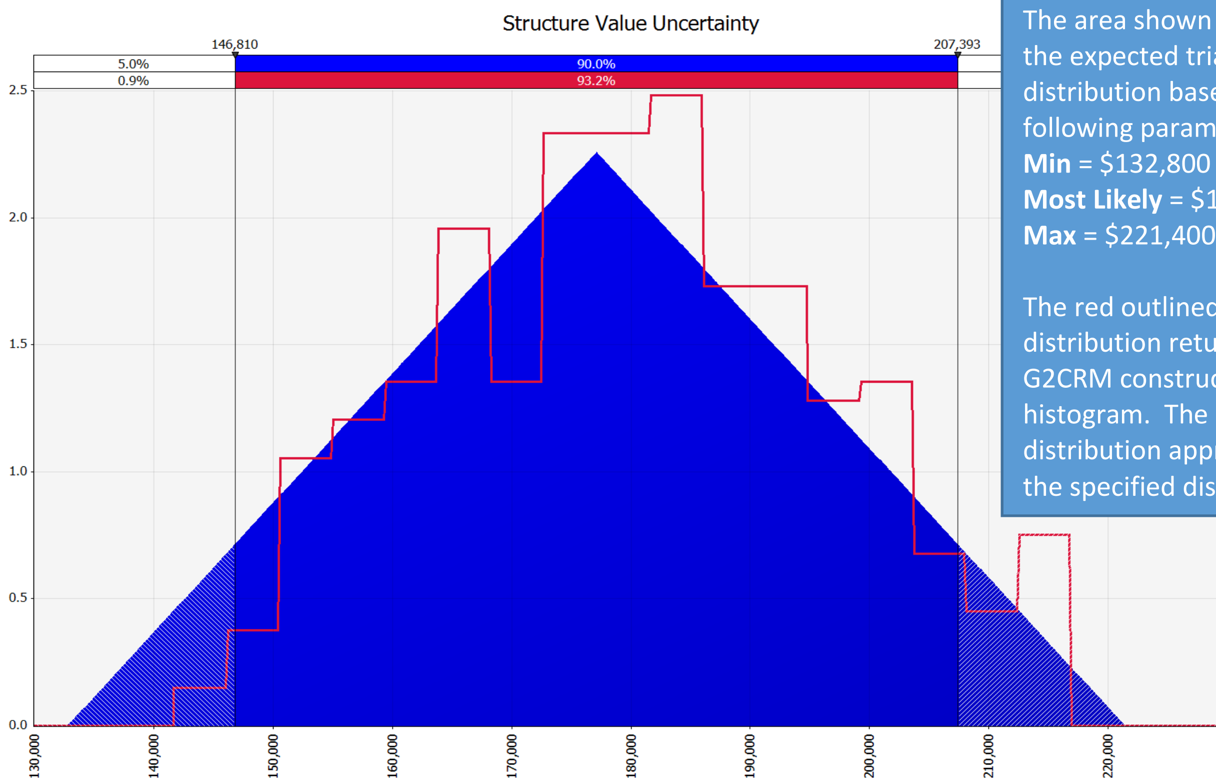


*Figure 10: Structure Value Uncertainty*

**Content Value Uncertainty**

The area shown in blue is the expected triangular distribution based on the following parameters:

**Min** = $79,700

**Most Likely** = $88,555

**Max** = $97,400

The red outlined area is the distribution returned by G2CRM constructed as a histogram. The returned distribution approximates the specified distribution.

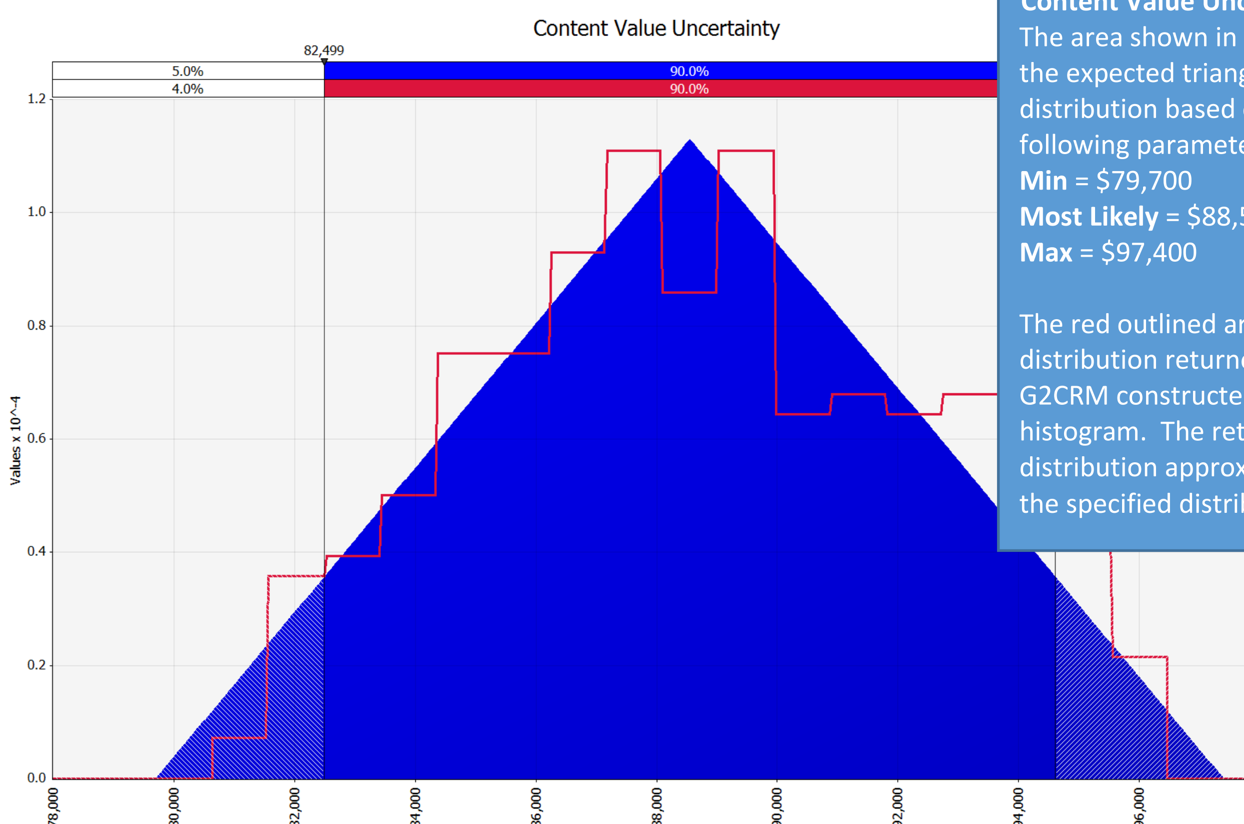


*Figure 11: Content Value Uncertainty*

### 2.9.6 Test-6 Sea Level Change Test

This test measured the relationship between damages and structures removed and sea level change. Model simulation parameters for this test were as follows:

- # Iterations = 10
- Rebuild Threshold = .50
- Damage Threshold = .25

The model provides the capability to run all sea level rise scenarios simultaneously (performance depends on PC memory and the number of processors).Table 8 provides details on the results as collected from the IterationSummary output file. All random variables depicted in Table 8 were averaged over the ten life cycles.

| IterationSummary Fields | Base | Intermediate | High |
|---|---|---|---|
| Number Storms In Iteration | 73.1 | 73.1 | 73.1 |
| Present Value Structure Damage | $272,945,163 | $286,355,510 | $317,762,403 |
| Present Value Contents Damage | $461,966,728 | $496,267,960 | $592,499,673 |
| Present Value Damage | $734,911,891 | $782,623,470 | $910,262,076 |
| Number Structures Removed | 1,418 | 1,571 | 1,859 |
| Initial Structure Value | $284,156,705 | $284,156,705 | $284,156,705 |
| Initial Contents Value | $193,200,084 | $193,200,084 | $193,200,084 |
| Final Structure Value | $157,509,957 | $137,201,011 | $94,665,688 |
| Final Contents Value | $115,114,178 | $100,778,371 | $67,000,755 |

*Table 8: Sea Level Change Results*

Results indicate that the model can incorporate sea level rise into damage estimates. Damages and the number of structures removed are positively correlated with the rate of sea level change. The actual level of sea level change at the time of each storm can be found in the "StormEvent" csv output file. These values can be tested against USACE guidance to ensure compliance. Figure 12 was developed from the "StormEvent" csv output for each sea level change scenario.

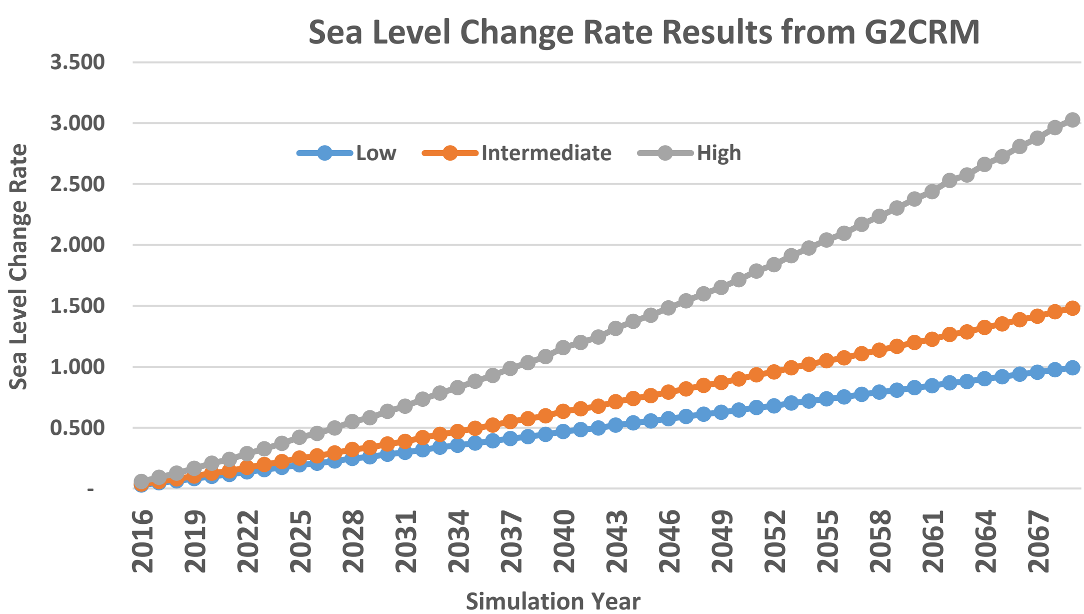


*Figure 12: Sea Level Change Comparison*

# 3 System Quality

"System quality refers to the quality of the entire system related to the development, use, and support of the model. The system includes the software used to develop the model and the hardware platform upon which the software is based. The quality of the system is ensured by system level functional testing of hardware and software system components, design verification planning for customer acceptance, third party interoperability, compatibility with various hardware and operating systems such as USB and Windows, and the development of problem tracking database." – EC 1105-2-412

## 3.1 Why was this software tool selected and was the selection appropriate?

G2CRM was selected for these two studies because of its ability to perform rapid development of a TSP planning level analyses while incorporating uncertainty and system change in a life cycle. The tool is designed to measure the impacts of storm influenced coastal flooding which is similar to the kind of damage drivers experienced in the study area. It is capable of incorporating tidal influences on water levels as well. This tool is appropriate for this application.

## 3.2 Is there any evidence of consequential source code errors?

During the course of the approval for use review, the model was run multiple times. No evidence of consequential source code errors was observed.

## 3.3 Is supporting hardware or software readily available to users or can it be readily provided?

The reviewer was able to get the model installed on an ACE-IT PC to conduct this review. However, the model is still under development and testing at this time and not widely available for field use.

## 3.4 Is there evidence of model testing and evaluation?

The model has been developed through a set of test situations using realistic data (representing situations in New Orleans, Diamondhead Mississippi, and Freeport Texas), but it has not as yet been applied for any Corps project (other than this one at the time of this writing) and is not currently certified. The model is under continuous development and evolution, with new capabilities being added to support additional coastal situations and analysis needs.

## 3.5 Are there critical errors that have not been corrected?

At the time of this evaluation there was no evidence of critical errors.

## 3.6 Can data be readily imported into other software analysis tools?

Model .csv outputs can be readily imported into MS Excel, MS Access, Matlab, and HEC Field Calculator. G2CRM utilizes a Spatialite database that can be accessed with Quantum GIS, ArcGIS[6], and the HEC Field Calculator. Python scripts are used to generate graphics.

# 4 Usability

"Usability refers to the ability to access the model, receive training to run the model, secure input data required for the model, run the model, obtain outputs from the model as well as receive documentation to guide the process and technical support if problems occur." – EC 1105-2-412

[6] See http://desktop.arcgis.com/en/arcmap/10.3/manage-data/databases/sqlite-and-arcgis.htm for using Spatialite with ArcGIS

## 4.1 What data is required to run the model?

Data is grouped into storm, system, and asset themes that contain spatial, topological, and attribute data. Storm Theme: 1) discrete individual storms with probability of occurrence for each storm. 2) Hydrographs of water level at important locations for each storm 3) Wave information for each storm (planned for future use. System Information 1) Boundaries & Characteristics of MAs; 2) PSE characteristics that comprise flow into and out of modeled areas Asset Information 1) Location, type, and value of structures and contents.

## 4.2 What evidence is there that data will be readily available to users?

Storm data is anticipated to come from data stored in the ERDC Coastal Hazards System (CHS). Protective system element layout and attribute data is expected to be in a GIS format. Asset data is expected to be available from the HEC developed National Structure Inventory (NSI) or local sources in a GIS format. Other data such as occupancy types and damage functions are populated in a spreadsheet template and imported back into G2CRM.

## 4.3 Are results presented in an understandable format?

The results are presented in an understandable format.

## 4.4 Are the results useful for supporting project analysis?

Yes. Results can be used to estimate inundation damages for future with and future without project conditions. The model provides the ability to describe alternatives, and the adjustments each alternative makes to a specific target.

## 4.5 Can the results be exported into project results?

Yes. The results can be exported into MS Access, MS Excel, MS Word, etc. Results can be used to build tables to describe project results. All tables and figures included within this document are based on G2CRM outputs imported into MS Access, MS Excel, and/or Quantum GIS.

## 4.6 Is user documentation available, user friendly, and complete?

There is no substantial user documentation available for the model at this time. The only document available to the reviewer at this time was the “G2CRM overview”. The model developer put together a series of videos that walk users through the development of a G2CRM model.

## 4.7 Is adequate tech support available for the model?

The model has not been rolled out for field use at this time. Therefore, there is no formal technical support aside from the development team available at this time. However, issues that were discovered during the course of the review were promptly addressed.

## 4.8 Is the software/ hardware platform available to most users?

The hardware is available to most users, but the software is currently still under development. Databases used for input and storage of results are Spatialite databases – an open source, freely distributable method for storing spatial and non-spatial data in a relational database.

## 4.9 Is the model easily accessible?

G2CRM is under development and is not easily accessible at the time of this writing.

## 4.10 Does the model allow for easy verification of calculations and outputs?

The model does allow for easy verification of calculations and outputs.

# 5 Conclusion

Based on this review, G2CRM is recommended for single use approval at this time. This model is suitable for use on coastal estuarine environments that are impacted by tropical and extra tropical storms and tidal influences.

# 6 Recommendations

## 6.1 Repetitive Damages

The greatest need is guidance on how repetitive damages should be handled. If the damage threshold is set too low, then the asset can be taken out of the inventory sooner than what is realistic. If the damage threshold is set too high, then in many cases a rebuild event is never triggered, and the structure accumulates many times its initial value over the course of the life cycle. The simplest way to address this would be to specify either globally, at the occupancy type level, and/or at the asset level a maximum level of damage attainable as a percentage of the structure value. Once this threshold is met, the asset is removed from the inventory and no longer allowed to accumulate damages.

## 6.2 Model Development Workflow

The reviewer was unable to open G2CRM model using existing model files developed on other machines. All models had to be developed from scratch. It would be useful to be able to link to existing files without having to build the model from scratch. According to the model developer there is a way to open existing model files without building it from scratch.

## 6.3 Output File Directory Structure

Currently when G2CRM generates outputs, it creates a new directory for each run and maintains a link to these runs in memory. This seems to add to the complexity of finding outputs and can use a large amount of hard drive space. The model seems to generate warnings when some these directories are deleted. It is recommended that users be given control of where outputs are stored and when new scenarios need to be created similar to other certified USACE corporate models (Beach-fx, Harbor Sym).

## 6.4 Output Rollups

It would be useful to be able to get summarized results by asset for a production run without having to generate an AssetDamageDetail file. For example, it could be called the “AssetDamageStatistics” file, and contain the asset, an count of the number of times the asset was damaged, and other summary statistics on structure, content, and total present value losses. If the model already has this capability, then instructions on how to extract it would be useful.

## 6.5 Users Documentation

Since the model is currently under development, it is understandable that there is no user’s manual at this time.  However, a manual that explains how to put together a G2CRM model and develop the model inputs is recommended.

## 6.6 Model Inputs / Data Entry

G2CRM allows a triangular distribution of the damage functions to be specified as an input to the model, however, that distribution was not represented in this application.  It is recommended that the triangular distribution for the damage functions be specified by the PDT so as to capture the damage function uncertainty. Also, when viewed in GIS with an aerial base-map, some of the assets did not correspond to locations with visible structures.